BOOSTER COLLIMATION AND SHIELDING

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OUTLINE

- Localizing Beam Losses
- Collimation System
- Integrated Collimators/Shielding
- Another 15 years at 2e17 p/hr

INTRODUCTION

Without collimation, beam loss rate in the Booster can be as high as tens W/m, approaching 100 W/m with the upgrade plans. This is substantially higher than the "good-practice" limit of 1 W/m. A two-stage beam collimation system with local shielding - designed and installed in early 2000's - provides adequate protection of the Booster components and environment by localizing operational losses. This system is a vital ingredient of any scenario for Booster operation for another 15 years.

COLLIMATION AND LOSS ASSUMPTIONS

The purpose is to localize proton losses in a specially shielded section, thus to reduce irradiation of the rest of the machine to the acceptable levels. Straight sections 6 and 7 were chosen because these regions are far from the engineering, support and office buildings.

At the time of the design, total beam losses in the Booster were as high as 20%. In simulation studies, it has been conservatively assumed that 30% of the beam is lost at injection (400 MeV) and 2% at 8 GeV.

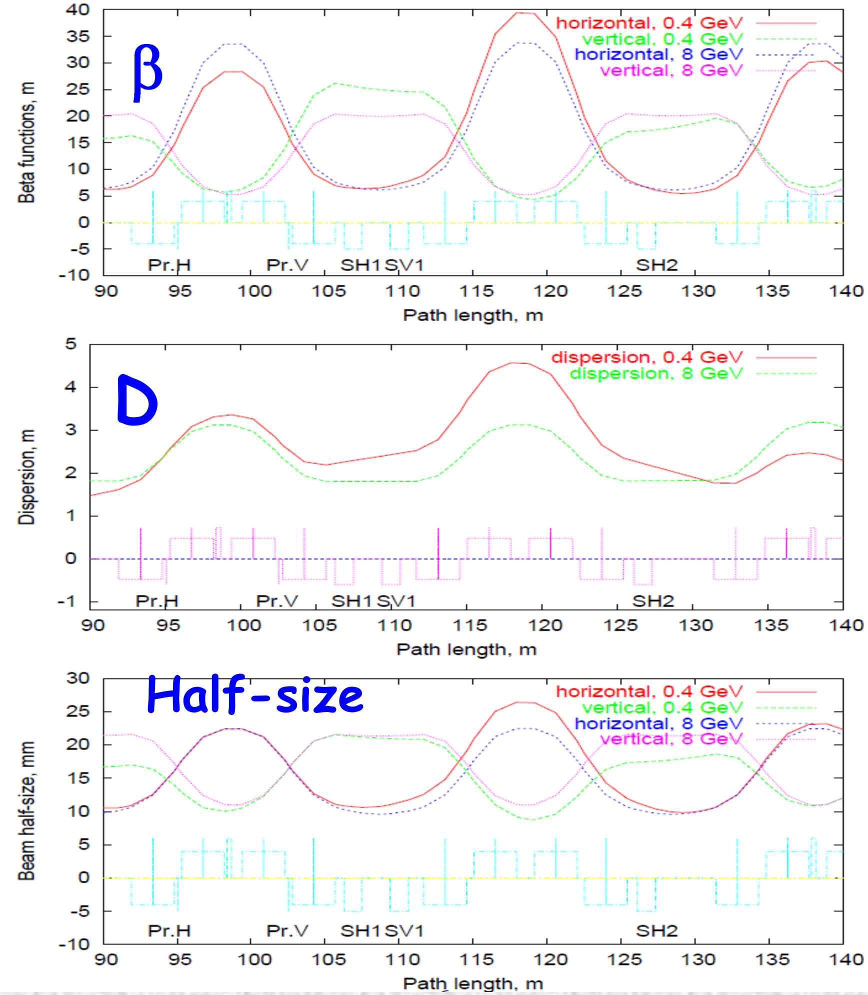
COLLIMATION SYSTEM (by Sasha Drozhdin)

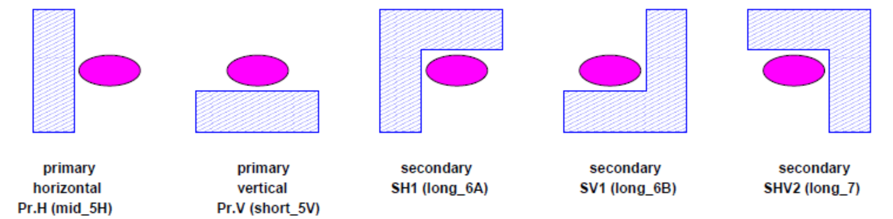
A 2-stage collimation system was designed with thin horizontal and vertical primary collimators (foils) followed by secondary collimators (0.6-m stainless steel). Foils are placed at the edge of the circulating beam after injection.

Secondary collimators are positioned with a 0.5σ offset with respect to the primary ones at phase advances that are optimal to intercept most of particles out-scattered from the foils during the first turn after the halo interaction with the foils (53^o and 143^o horizontal, 21^o and 124^o vertical).

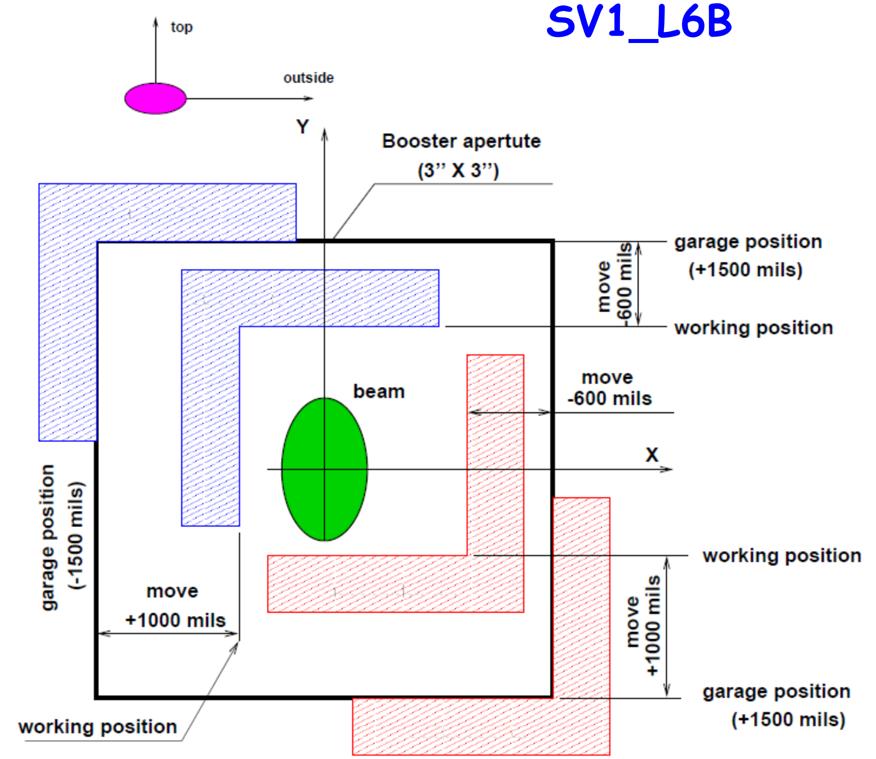
LAYOUT (STRUCT by Sasha Drozhdin)

PH_M5 PV_S5 SH1_L6A SHV2_L7

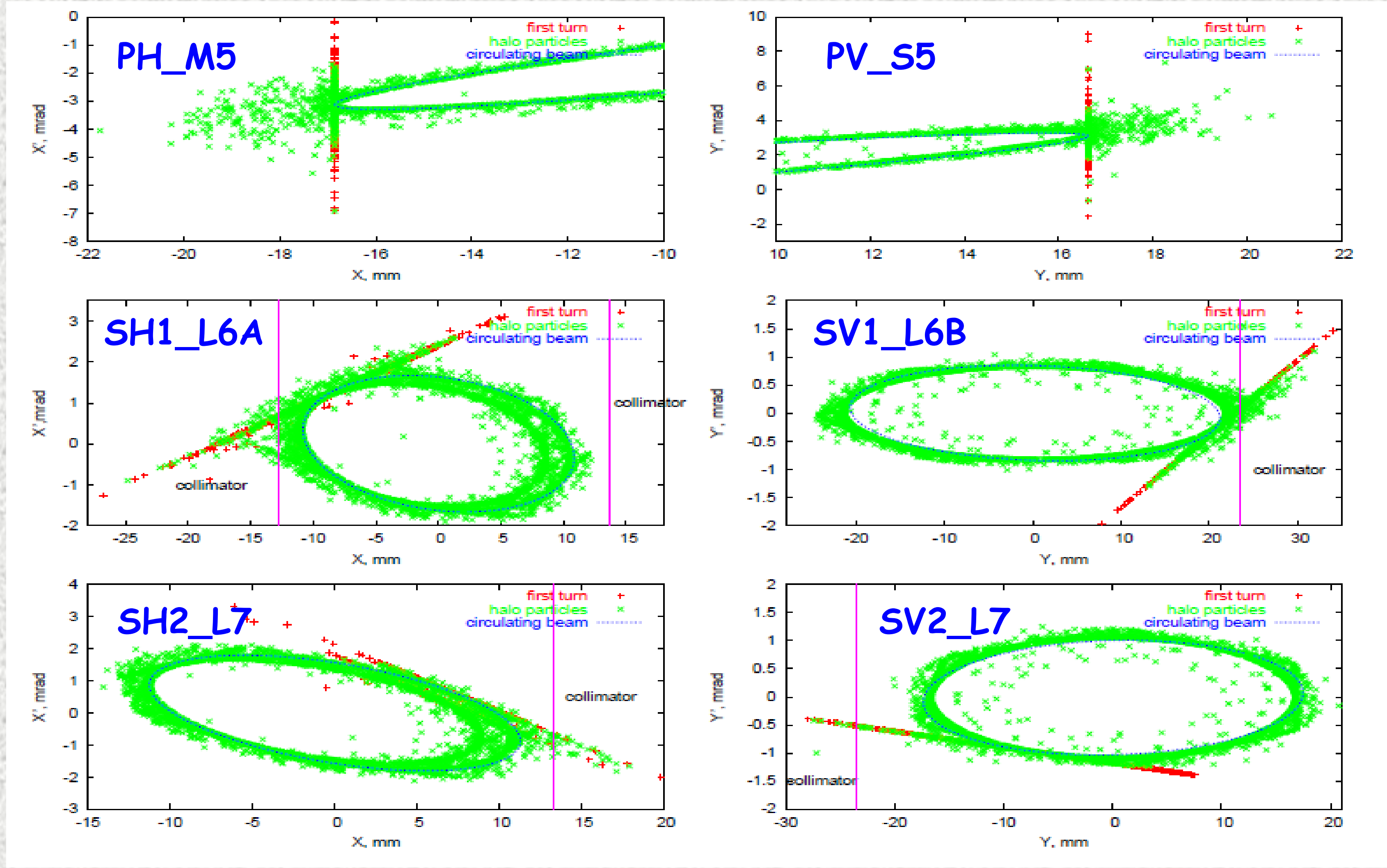




SV1_L6B

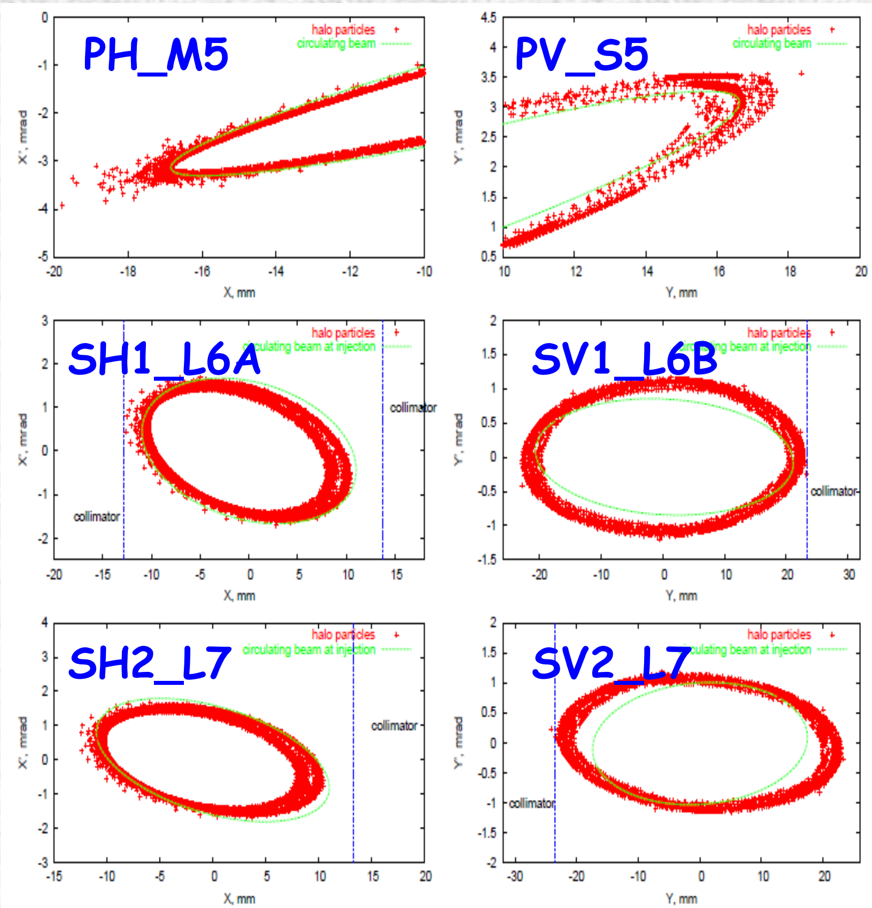


400-MeV Injection: 0.3-mm Carbon Primary

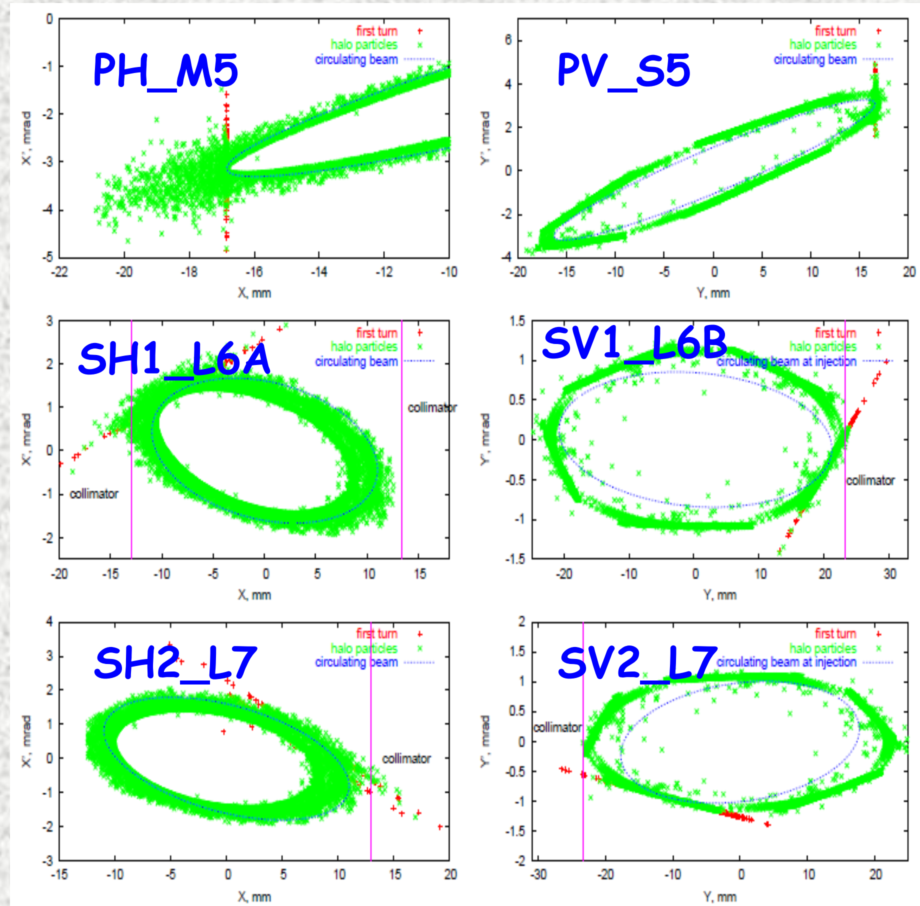


STRUCT

Carbon vs Tungsten Primary Collimators at 8 GeV



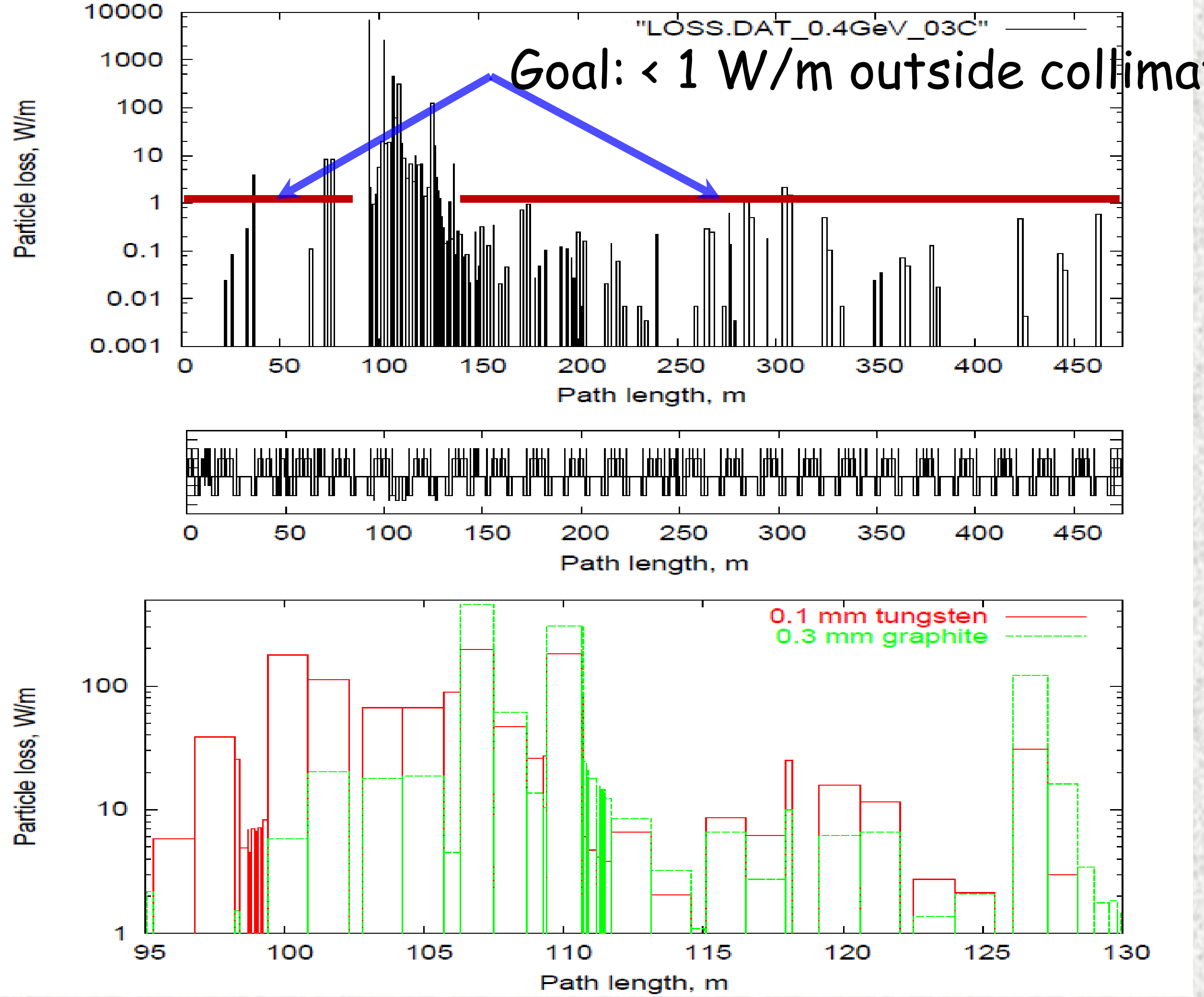
0.3-mm C



0.1-mm W

STRUCT

Calculated Beam Loss Distributions at Injection



0.3-mm C primary foil

0.1-mm W

0.3-mm C

STRUCT

PRIMARY COLLIMATORS AND EFFICIENCY

In simulations, the highest collimation efficiency is achieved and beam loss rate at injection even immediately downstream of the primary collimators can be kept at 1W/m level if the scatterer thickness is changed during the cycle from 0.003 mm to 0.1 mm for tungsten or from 0.15 mm to 5.4 mm for carbon (wedge disk?).

Such a system would localize about 99% of beam loss in a 25-m long region. Beam loss in the rest of the machine is on average 0.1 W/m, with several peaks of ~1 W/m.

Reality: Chosen/Installed 0.381-mm Copper foil

BEAM LOSS MODEL: from STRUCT to MARS

Beam: 5e12 ppp at 10 Hz → 1.8e17 p/hr

Total beam loss: 30% at 0.4 GeV and 2% at 8 GeV

STRUCT Results:

0.4 GeV:	20% in L6, 1e13 p/s: 0.7 L6A(H) + 0.3 L6B (V)
	10% in L7, 5e12 p/s: SHV2_L7
8 GeV:	1% in L6, 5e11 p/s: 0.7 L6A(H) + 0.3 L6B (V)
	1% in L7, 5e11 p/s: SHV2_L7

Current goal: 2e17 p/hr

and losses are much lower than 10 years ago

SHIELDING: LIMITS AND DESIGN CONTRAINTS

- Prompt dose equivalent *DE* < *5 mrem/hr = 0.05 mSv/hr*
  at peak, 13.5 feet of dirt above the tunnel
- Sump water activation $\langle S \rangle_{gravel} < 4000\ cm^{-3}s^{-1}$
- Residual dose rate $P_\gamma < 100$ *mrem/hr = 1 mSv/hr*
  at 1 foot in tunnel (30 days / 1 day) → hands-on maintenance
- Accumulated absorbed dose in magnets, cables, motors, instrumentation → lifetime
- Energy deposition in collimators: jaw integrity, cooling
- LCW pipe activation; air activation

COLLIMATOR-SHIELDING: ISSUES

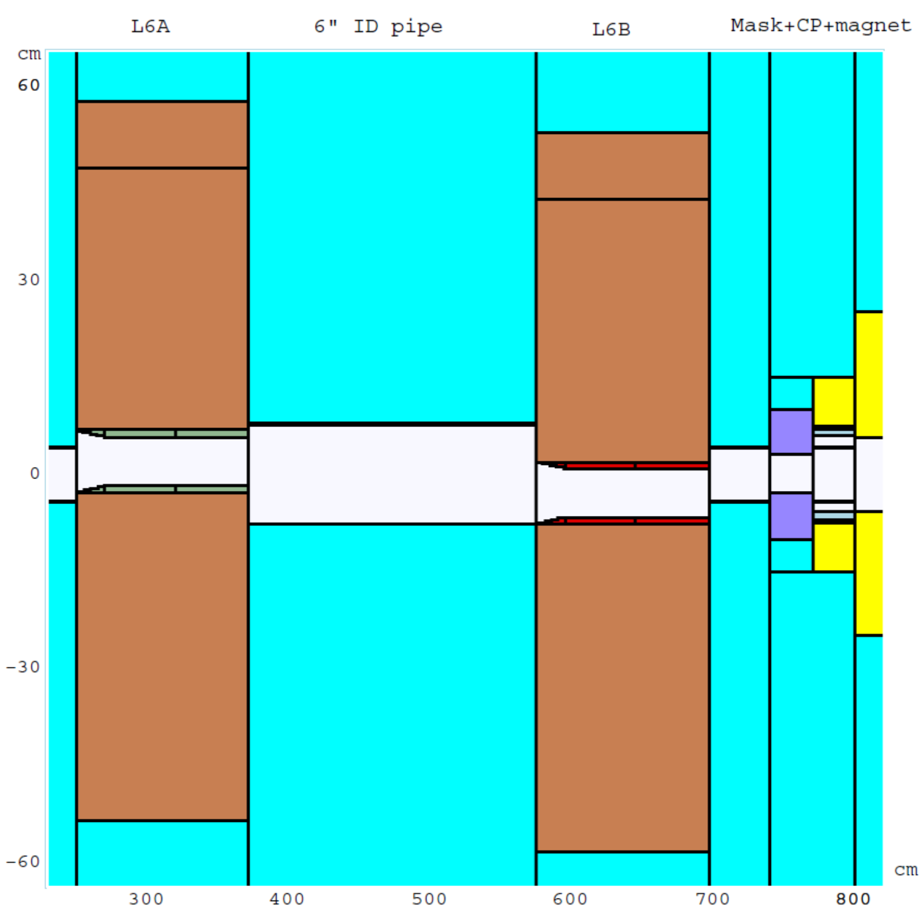
The original design consisted of L-shaped copper jaws brazed to a beam pipe. Stands and motors were designed to allow lots of room to stack steel shielding. There were, necessarily, rather large gaps between the jaws and shielding allowing radiation to escape the core, activate air and increasing the shielding dimensions. To access the collimator itself in the event of a catastrophic failure would require removing the shielding and exposing a very hot object.

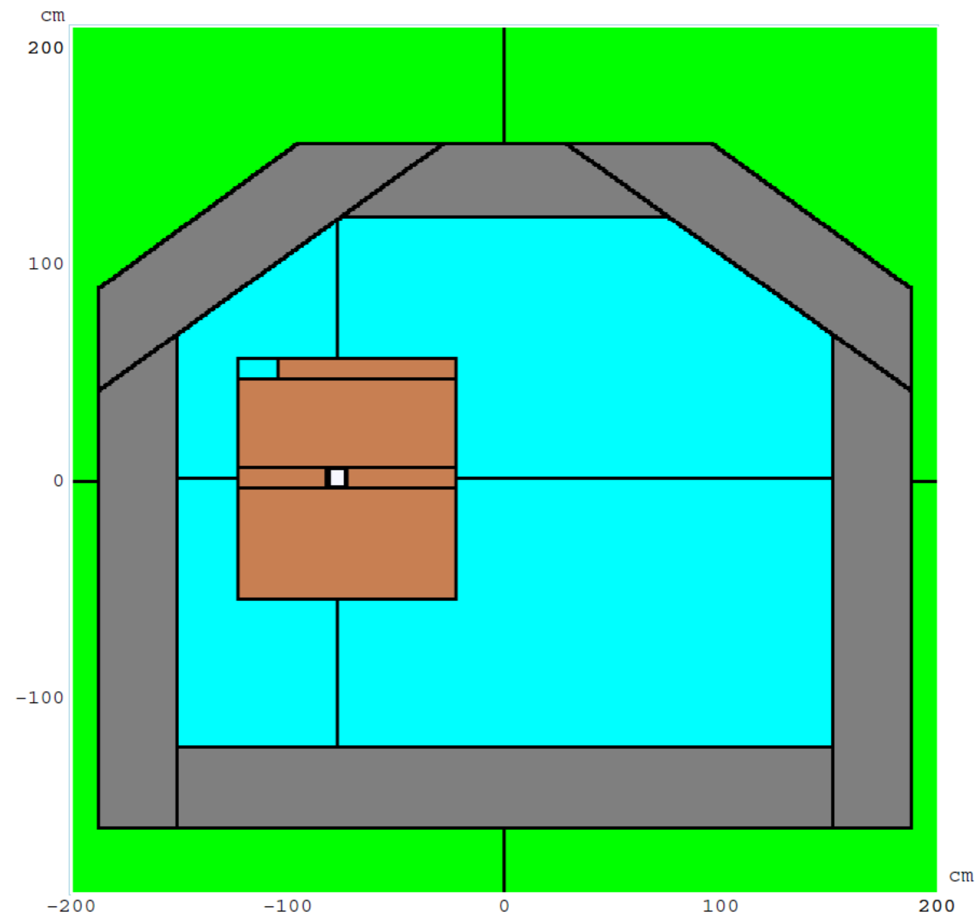
INTEGRATED COLLIMATOR-SHIELDING

The solution was an integrated collimator-shielding system best w.r.t. efficiency, space and alignment. In that design, all failure prone components are outside the shielding. This module is rather compact (approximately 1x1x1 m^3 outside) and uniform, with no cracks and gaps, eliminating the air activation problem.

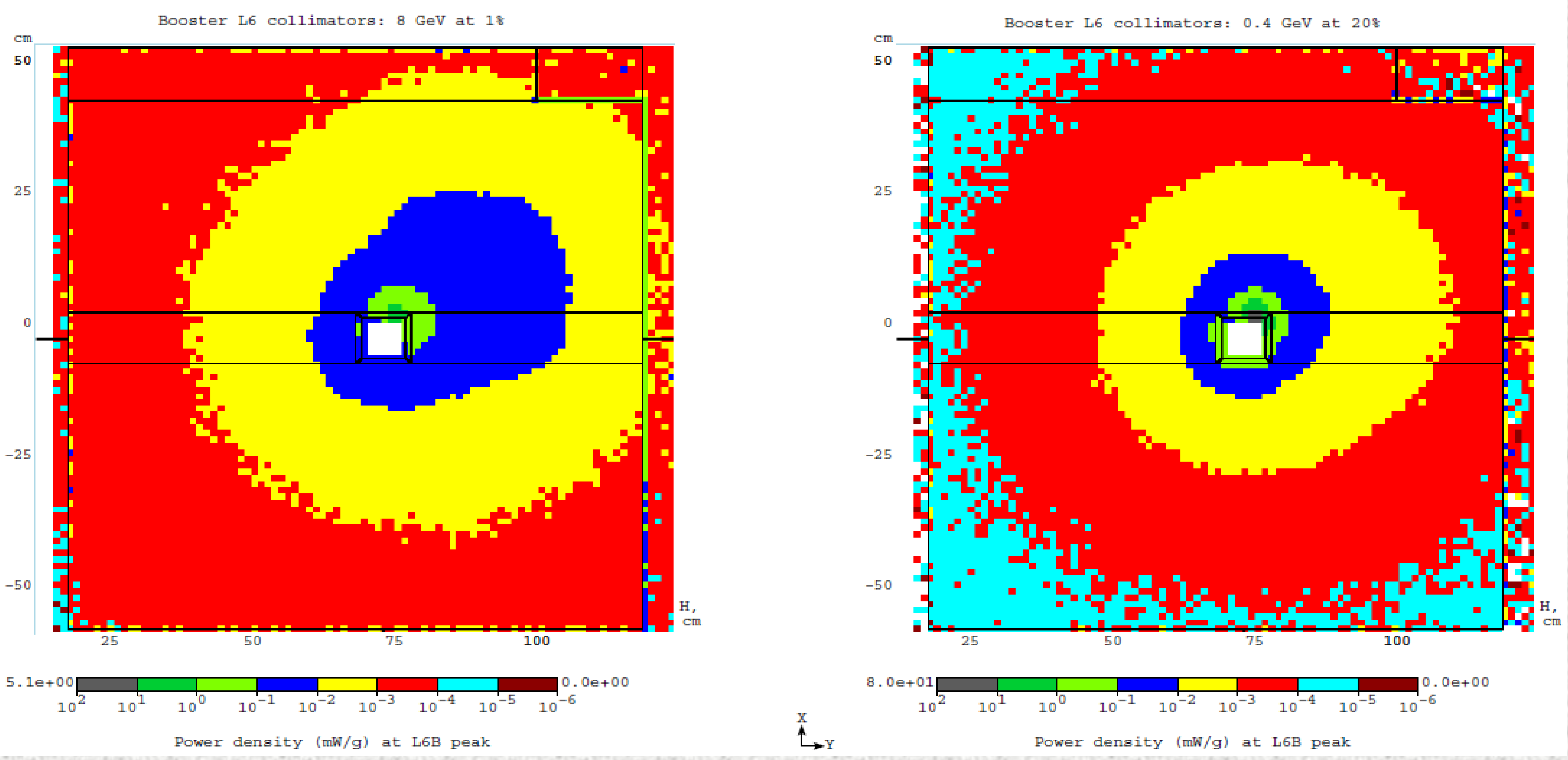
Because of the tight integration of the collimator and shielding steel, both the collimator and the surrounding shielding move as a unit. The actuators are sized to move the 11.6 ton block, a typical weight for remotely operated magnet stands.

OPTIMIZED MARS MODEL (5 iterations)



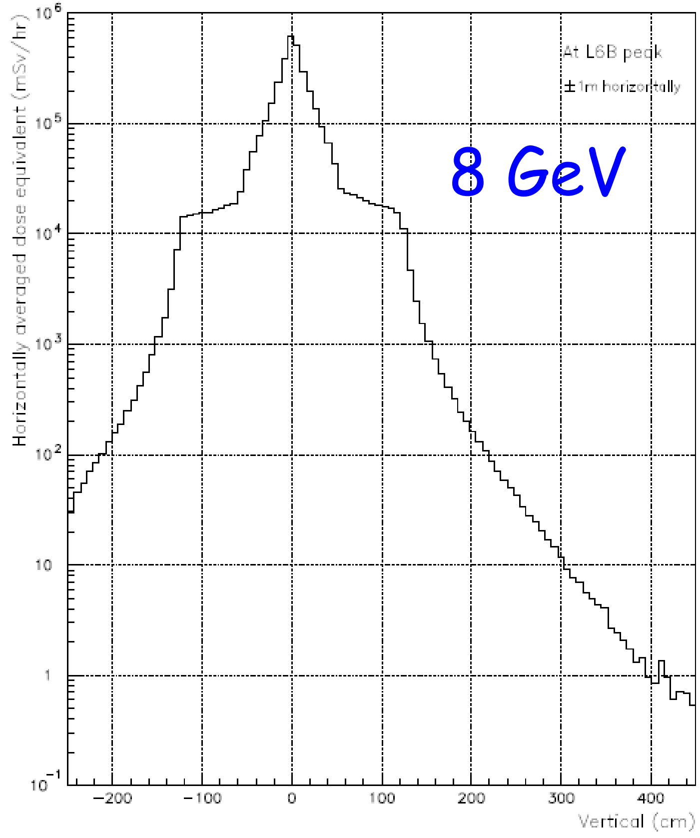


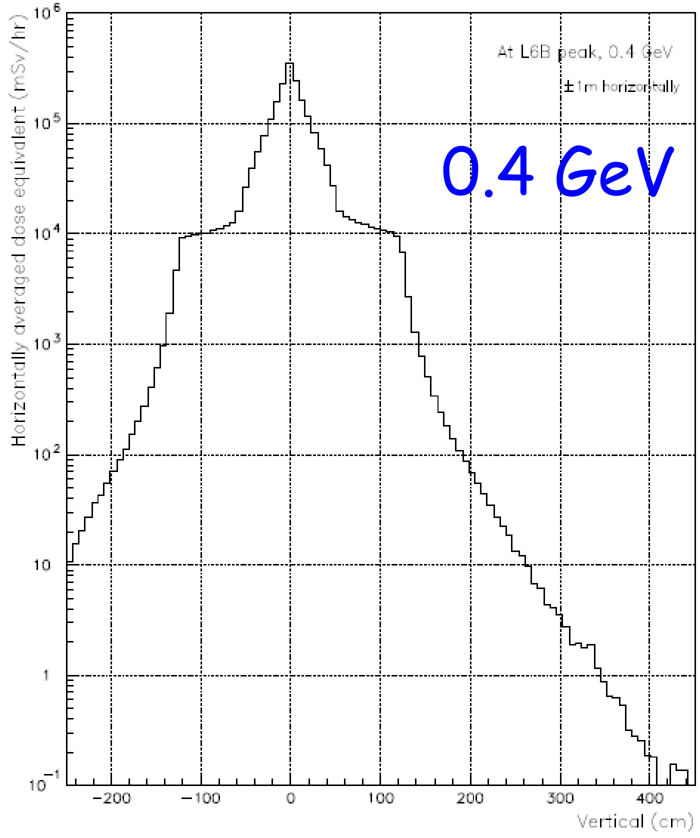
Power Density at Shower Max in L6B at 8 and 0.4 GeV



Total beam loss in L6 is 640 W with 450 W in L6A+L6B collimator/shield.
ANSYS: **no cooling is needed** (T_{ss} = 60°C); **no mechanical issues**;
the jaws withstand 25 pulses over 2.5 s at 8 GeV.

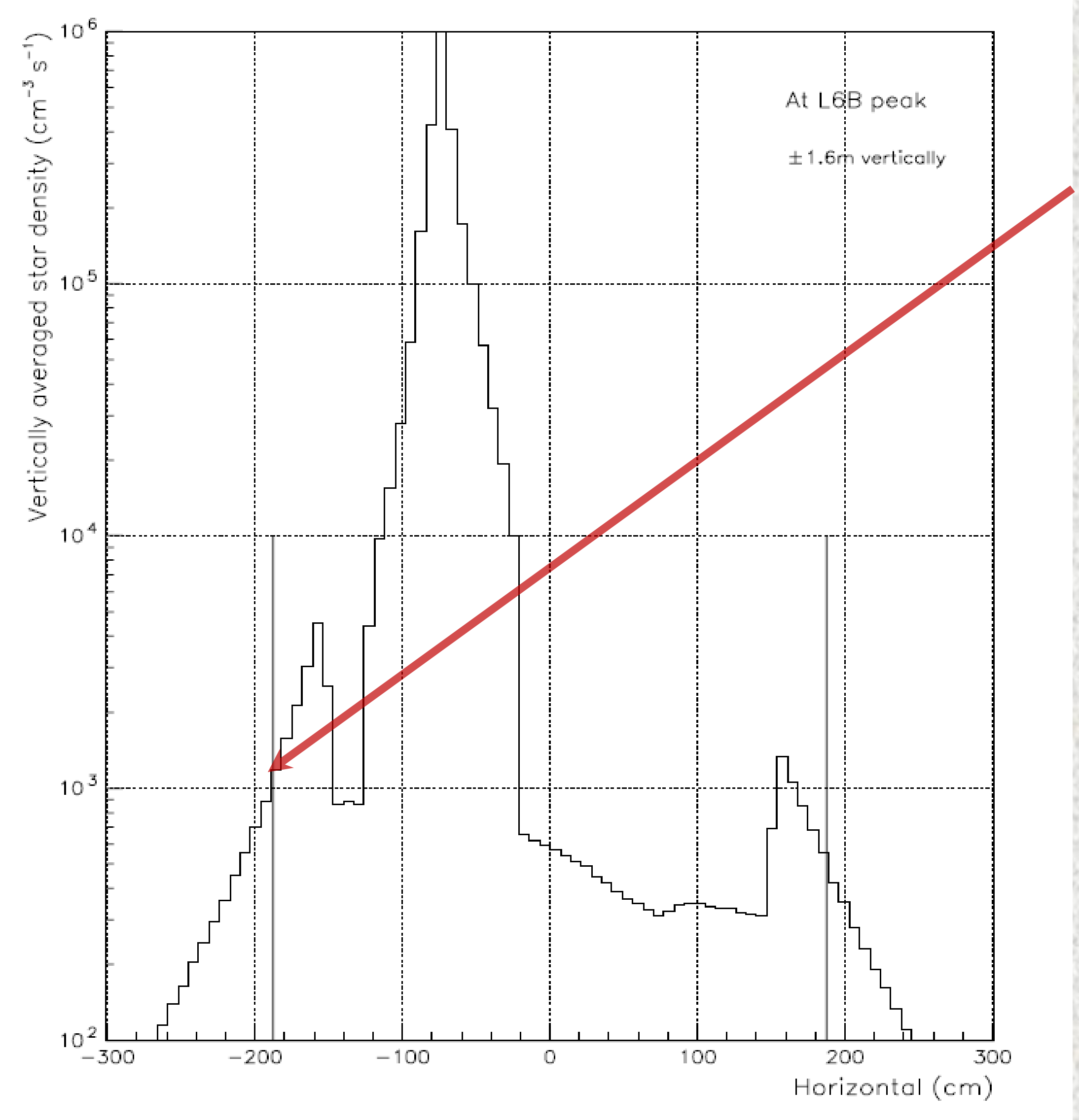
PROMPT DOSE ABOVE L6





Cumulative peak dose above L6 after 13.5 feet of dirt: 0.01 (8 GeV) + 0.0025 (0.4 GeV) = 0.0125 mSv/hr = 1.25 mrem/hr < 5 mrem/hr, i.e. **4 times below the limit**

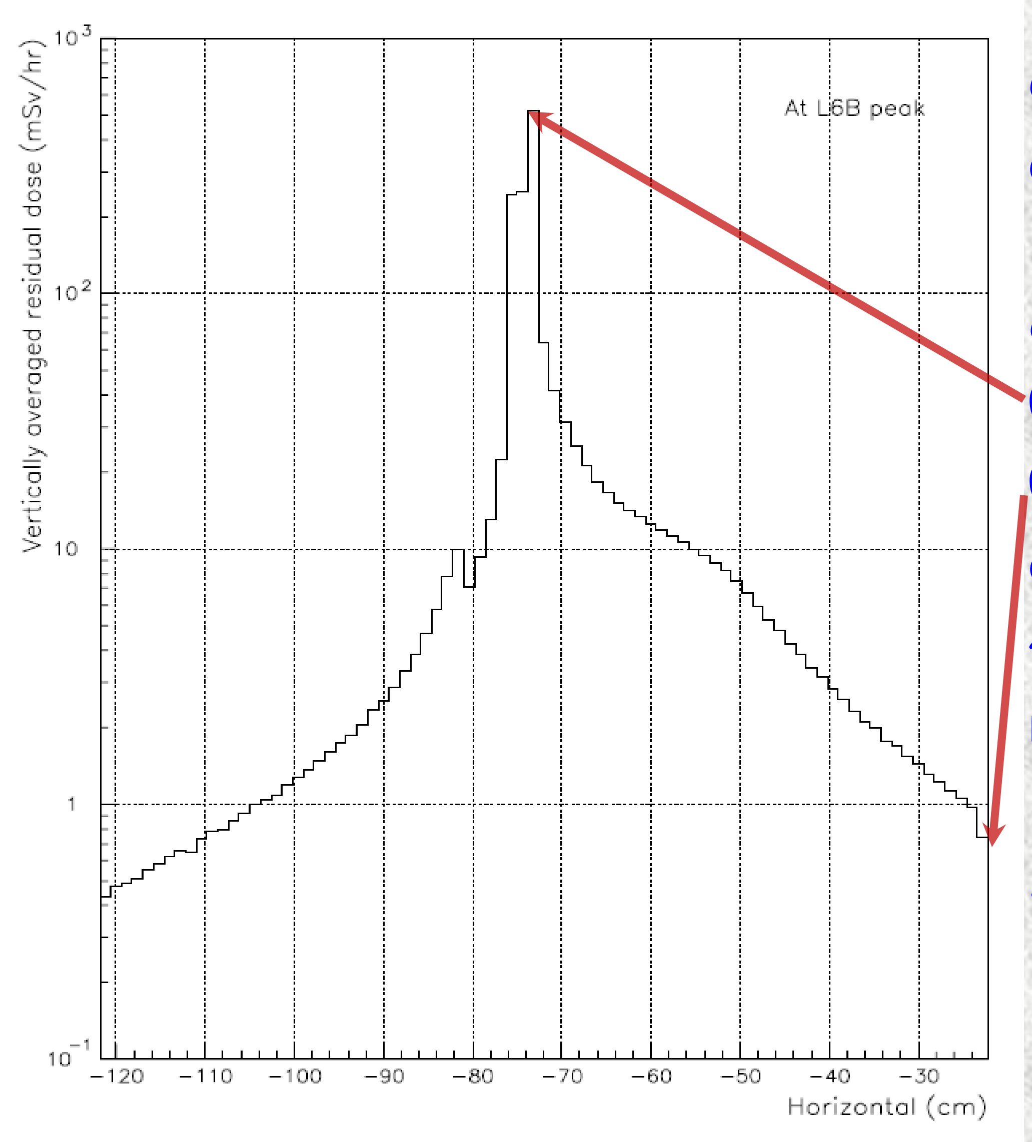
SUMP WATER ACTIVATION



Peak cumulative average star density immediately outside the tunnel walls is 1163 cm^{-3}s^{-1}, i.e. **3.5 times below the limit**. Scraping at injection gives 30% of this value.

In reality, the **margin is 2 to 3 times better** if one averages over the gravel fill surrounding the tunnel.

RESIDUAL DOSE RATE



Cumulative residual dose on contact after 30-day irradiation and 1-day cooling:
0.5 Sv/hr (50 R/hr) on jaws;
0.3–1 mSv/hr (30-100 mR/hr) on shielding outside (design goal);
40 mSv/hr on bare beam pipe right after L6A and L6B.

Scraping at injection gives 15-25% of these values.

ABSORBED DOSE: COMPONENT LIFETIME

Yearly absorbed dose at the L6B longitudinal peak is about 20 MGy/yr (**1 MGy = 100 Mrad**) on the jaws, 40 kGy/yr on shielding outside and up to 10 kGy/yr at walls, ceiling and floor. The maximum absorbed dose in the CP inner coils varies azimuthally from 0.3 to 4 MGy/yr that can reduce their lifetime.

It was found that a simple 30-cm long steel mask (7.6 cm ID, 30 cm OD) between L6B and CP reduces the accumulated and residual doses by up to a factor of four.

Limits:

50 MGy (kapton, polymide), 20 MGy (G11), 10 MGy (epoxy),

10 MGy (mylar), 0.1-10 MGy (electrical insulation)

SUMMARY

- Booster beam collimation system integrated with shielding provides adequate protection of the components and environment.
- It was designed for beam of 5e12 ppp at 10 Hz, i.e. for 1.8e17 p/hr, and conservative beam loss model (30% at 0.4 GeV and 2% at 8 GeV).
- With that, it is fully compatible with the 2e17 p/hr goal for next 15 years w.r.t. its efficiency, prompt dose on ground surface, sump water activation, and residual dose rates in the tunnel.
- Collimation region component lifetimes seem OK but need a closer look (masks, magnets, primary collimators).